

SEARCHES AND PROSPECTS FOR THE STANDARD MODEL HIGGS BOSON AT THE TEVATRON

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We summarize the status of SM Higgs boson searches at the upgraded Fermilab Tevatron performed by the CDF and DØ collaborations, with an emphasis on measurements at large Higgs mass, and derive sensitivity prospects for the upcoming increase in integrated luminosity.

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1. Introduction

The Higgs boson is the only elementary scalar particle expected in the standard model (SM). Its discovery would be a major success for the SM and would provide new experimental insights into the electroweak symmetry breaking mechanism. Direct measurements at LEP have excluded a SM Higgs boson with a mass $m_H < 114.4$ GeV at 95% C.L. but constraints from precision measurements nevertheless favor a Higgs boson sufficiently light to be accessible at the Fermilab Tevatron Collider. The current preferred m_H value, as deduced from a fit to electroweak measurements by the LEP, SLD, CDF, and DØ experiments ¹ is 85^{+39}_{-28} GeV. Combining with the direct limit, yields a 95% C.L. upper limit of 199 GeV. At the Tevatron, indirect searches for the Higgs boson involve precision measurements of the masses of the top quark and W boson, while direct searches require high luminosity samples for discovery or exclusion in the 115 – 185 GeV mass range, as shown in Fig. 1. At the Tevatron $p\bar{p}$ collider ($\sqrt{s}=1.96$ TeV), the two dominant mechanisms for Higgs production are gluon fusion, $gg \rightarrow H$, and associated production with a W or Z boson, $q\bar{q} \rightarrow W/Z + H$. The gg fusion process has the largest cross section, ~ 1 pb at $m_H=115$ GeV, but it is the most sensitive production mode only at rel-

atively high mass, $m_H > 135$ GeV, where it has a dominant branching ratio in WW^* . At lower masses, the dominant decay $H \rightarrow b\bar{b}$ is swamped by multijet background, so only the search for a Higgs produced in association with a vector boson has sufficient sensitivity in this mass region.

Two simulation studies have been performed before the "real" start of Run II to determine the sensitivity of the Tevatron experiments to SM Higgs physics. The first study, in '98-99 ², explored the whole mass range available with some approximation of the detector response, while the second one (HSS, in '03) was restricted to the low mass region ³ and used a more realistic simulation, since the first data of Tevatron Run II had

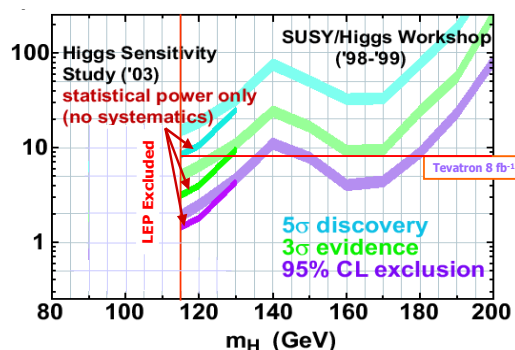


Fig. 1. Expected sensitivity to the Higgs boson at the Tevatron a function of m_H and luminosity.

become available. The second study essentially confirmed the findings of the original study, and both results are summarized in Fig. 1, after combination of all channels of both experiments. The conclusions were that the estimated integrated luminosity needed for a Higgs discovery at $m_H = 115$ GeV is approximately 8 fb^{-1} . Evidence at 3σ might be found with $3 - 4 \text{ fb}^{-1}$, while most of the Higgs mass region below ~ 185 GeV could be excluded at 95% CL with $\sim 8 \text{ fb}^{-1}$. The current results presented here below use about 10% of the final luminosity which will be delivered. We are thus now able to determine experimentally in which region the Tevatron is competitive with the foreseen luminosity as discussed at the end of this summary, after a brief review of the machine performance, new Higgs search results and their combinations.

2. Tevatron Prospects

The Higgs searches are crucially dependent on performance of the Tevatron accelerator and detectors, and the detectors are currently performing close to their optimal design values. The machine also is performing very well since the end of 2003, with close to designed delivered luminosities. As of today, about 2 fb^{-1} have been delivered, with weekly integrated luminosity routinely exceeding 20 pb^{-1} . Since this figure is the terminal value assumed in the minimal (so-called “base”) luminosity expectation (cf Fig. 2a), the current performance ensure that a minimal integrated luminosity of 4 fb^{-1} will be achieved by the end of 2009, as shown in Fig. 2b. If the accelerator keeps following the designed luminosity evolution, an integrated luminosity of about 8 fb^{-1} will be achieved, rendering the potential for a Higgs discovery significant at the Tevatron.

3. Searches for SM Higgs

The searches at low mass in the WH and ZH production channels have been presented in

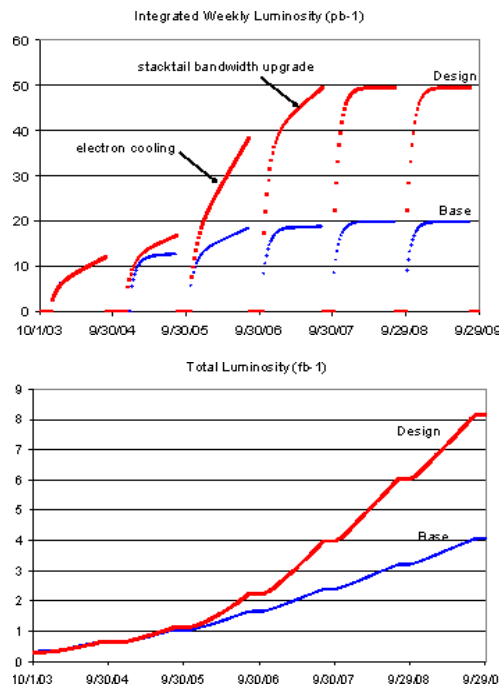


Fig. 2. Weekly and total expected integrated luminosity of the Tevatron as a function of time.

detail at this conference in Ref. ⁴, so we concentrate here on new results obtained assuming a large Higgs Mass (> 135 GeV). Two production channels have been exploited so far: $p\bar{p} \rightarrow WH \rightarrow WWW^*$, giving a final state with 2 like-sign leptons, and $p\bar{p} \rightarrow H \rightarrow WW^*$ which gives a final state with 2 opposite-sign leptons. In the WWW^* channel, DØ has presented its published results on 0.4 fb^{-1} ⁵: after preselection, 34 like-sign events ($ee, e\mu, \mu\mu$) are left, compared to a background of 34.9 events, dominated by instrumental background, in particular by events in which one of the lepton charge is misreconstructed. A topological likelihood discriminant based on 3 kinematic variables is then used to achieve further data reduction, with a final number of observed vs. background events of 6 vs. 4.4. In the absence of signal, the 95% C.L. upper limit on $\sigma(WH) \times BR(H \rightarrow WW)$ varies between 3.2 and 2.8 pb for m_H between 115 and 175 GeV.

Although it is not the most sensitive channel in any mass range, this channel provides additional sensitivity in the 130–150 GeV m_H range. There was low sensitivity expected in this mass region (Fig. 1), but with this search, the prospects in this area have now improved.

In the and $H \rightarrow WW^*$ channel, CDF and DØ have already published results on samples of 0.35 fb^{-1} , and obtained cross section limits of 3.5 pb^{-1} at $m_H = 160 \text{ GeV}$ ^{6,7}, where the SM expectation is 0.3 pb . At this conference, DØ has presented updated results with $\sim 1 \text{ fb}^{-1}$ of data⁸. The search is similar to the published ones, with a selection based on 2 isolated opposite-charge leptons + missing transverse momentum, and further kinematic cuts to reduce the background, which is dominated by WW production. The number of events observed is 37, to be compared to 44.5 expected from SM background, and 1.7 for a SM Higgs with $m_H = 160 \text{ GeV}$. The expected and observed limits are displayed in Fig. 3, and the limit at 160 GeV has been reduced to 1.6 pb , i.e. only a factor ~ 5 away for the SM Higgs prediction. This result also excludes a SM with

hance by a factor ~ 8 the Higgs production via the standard triangle diagram ggH ⁹ in the region of the search, assuming the most unfavorable case (infinite mass of the 4th generation quarks).

4. Combined Limits on SM Higgs

Both experiments have done the measurements in all channels, so the limits can be improved by combining all channels into a single limit. To do that, CDF follows a Bayesian approach, while DØ uses the CL_s method developed for the Higgs search at LEP, see Ref. ¹⁰ for details and complete references. The CDF (DØ) results and their combinations are displayed in Fig. 4a(b).

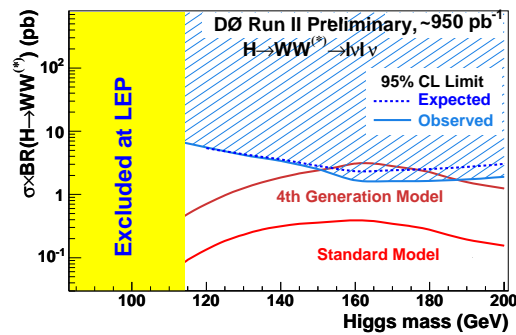


Fig. 3. WW^* results at DØ with $\sim 1 \text{ fb}^{-1}$ of integrated luminosity, compared to the SM and to its extension with a 4th generation.

4 families, having a Higgs with mass between 150 and 185 GeV, as shown. Indeed, the quarks of the putative 4th family would en-

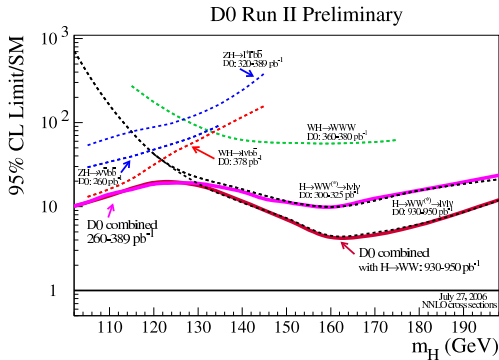
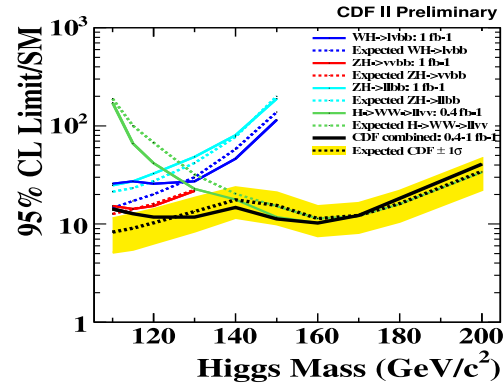


Fig. 4. 95% C.L. limits on Higgs production cross section, divided by the SM expectation, as a function of m_H , for individual channels and their combination of a) CDF and b) DØ. A ratio of 1 is equivalent to a 95% C.L. exclusion.

Both combination methods have then been applied to the combination of the results of both experiments and the resulting limits were found equal within 10%. The result of the CDF–DØ combination is shown in Fig. 5. Also shown are the “expected” limits for the CDF–DØ combination, and for the CDF and DØ separate combination, i.e. the limits assuming that the observations would be exactly equal to the SM background expectations. The expected limits of CDF and DØ have different shapes, since presently CDF has analyzed the low Higgs mass channels on a large dataset ($\sim 1 \text{ fb}^{-1}$) and the high mass on a small dataset ($\sim 0.3 \text{ fb}^{-1}$), while DØ has done exactly the reverse, so in fact the global curve corresponds to a good approximation to the curve of a single experiment with 1.3 fb^{-1} for all channels. The expected limits, which allow to judge the current sensitivity, show that at 115 (160) GeV, the limit is 7.6 (5.0) times higher than the SM expectation. The increase to the expected design integrated luminosity will reduce these values by approximately a factor 3.5, so a further gain in sensitivity of about 2.2 (1.4) is needed in data analysis to reach exclusion at these mass points. Separate studies already performed in the two experiments show that this gain will definitely be greater than 2.5 at low mass (use of Neural Net techniques in selection and in b -identification, better dijet mass resolution, increased acceptance, reduced systematic errors and inclusion of τ channels) and 1.7 at high mass (where b -identification and dijet mass resolution do not play a role). With further developments under test, or already used in other analyses, the full mass range between 115 and 185 GeV will be sensitive to an exclusion (or an evidence) at the 95% C.L. and at more than 3σ level in the most sensitive regions (~ 115 or 160 GeV).

In conclusion, the SM Higgs searches in all the channels are now being regularly updated and combined. We expect that af-

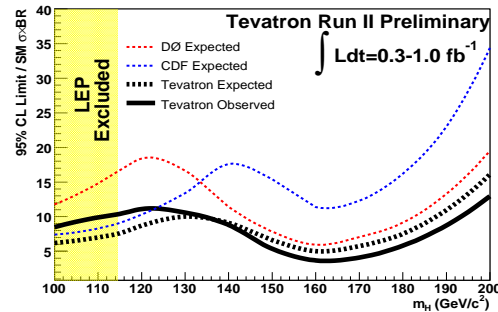


Fig. 5. CDF and DØ 95% C.L. expected and observed combined limits on Higgs production cross section, divided by the SM expectation, as a function of m_H . The expected limits for CDF and DØ separately are also given for comparison.

ter implementing the analysis improvements mentioned above, the sensitivity prospects will be met. Hence, the prospects for uncovering the first evidence of a light mass Higgs boson with $4\text{--}8 \text{ pb}^{-1}$ of Tevatron integrated luminosity are real.

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